High p_T Results from STAR

Thomas Peitzmann
Universiteit Utrecht
Utrecht University/NIKHEF
NIKHEF
for the STAR collaboration

Outline

- High-p_T Inclusive Spectra
- High-p_T Dihadron Correlations
- Intermediate-p_T Near-Side
- Intermediate-p_T Away-Side
- Heavy Flavour
- The Future: Photons

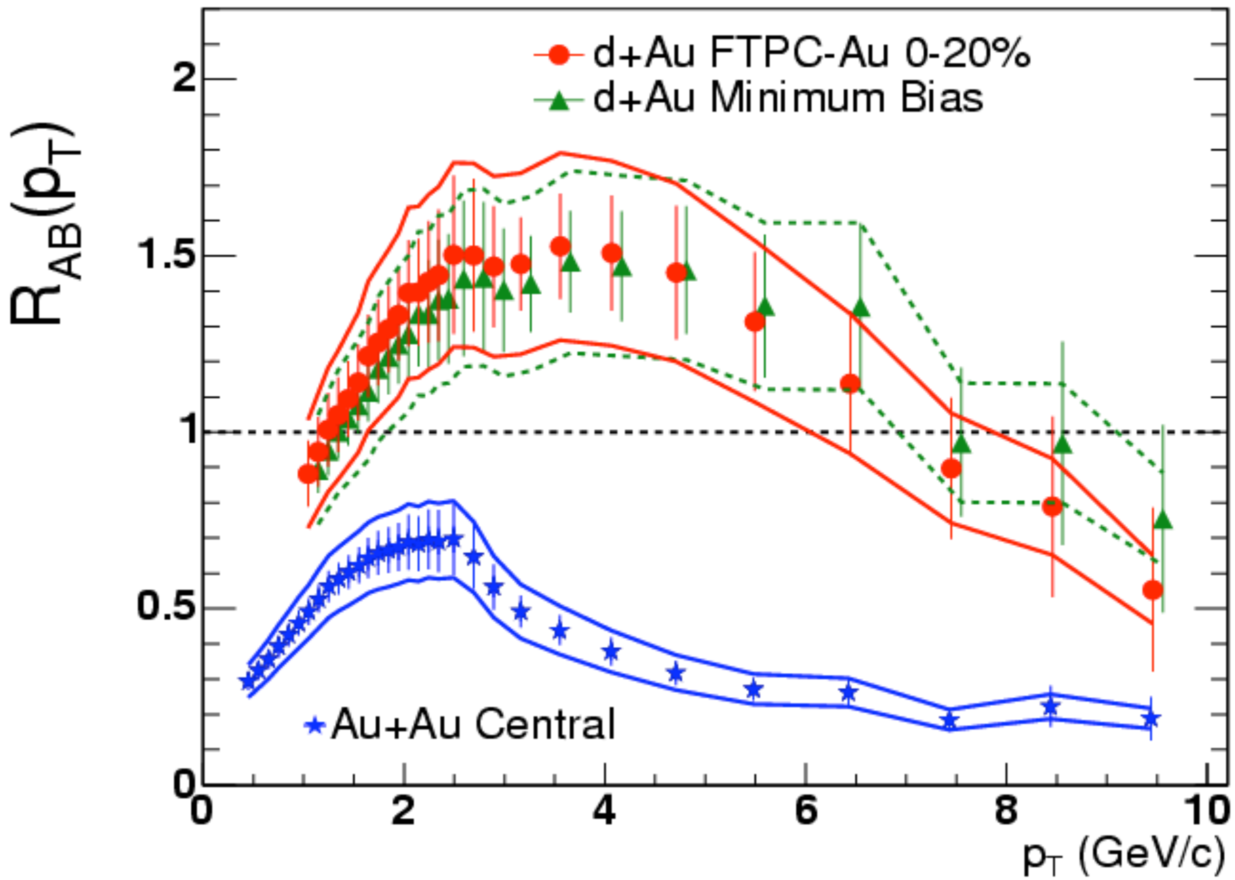
High-p_T Inclusive Spectra

Where's the fragmentation regime?

What's the lower limit on the medium density?

Inclusive Suppression

J. Adams et al, Phys. Rev. Lett. 91 (2003) 072304

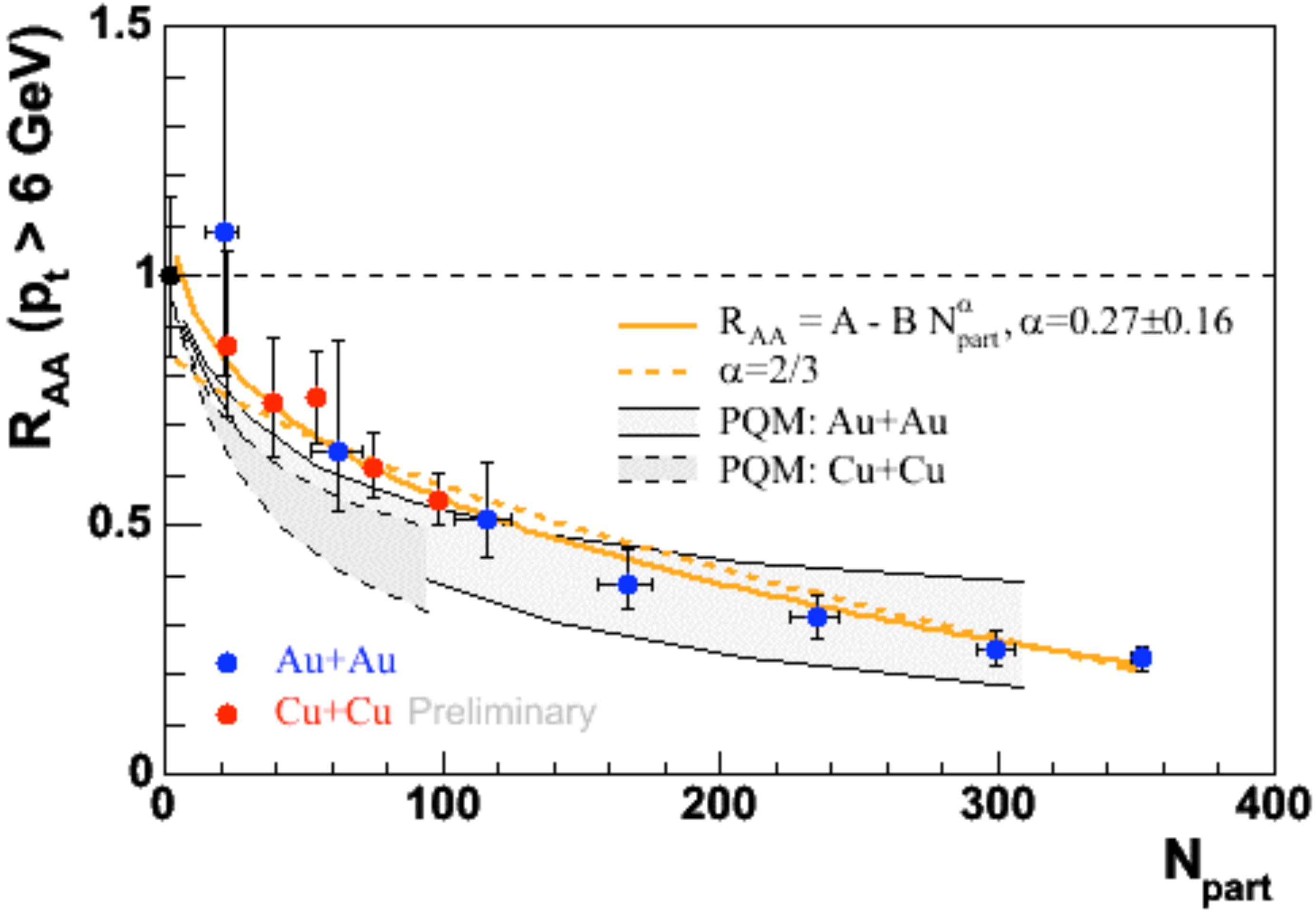


- studied with nuclear modification factor

$$R_{AA}(p_T) = \frac{d^2N^{AA} / dp_T d\eta}{T_{AA} d^2\sigma^{NN} / dp_T d\eta}$$

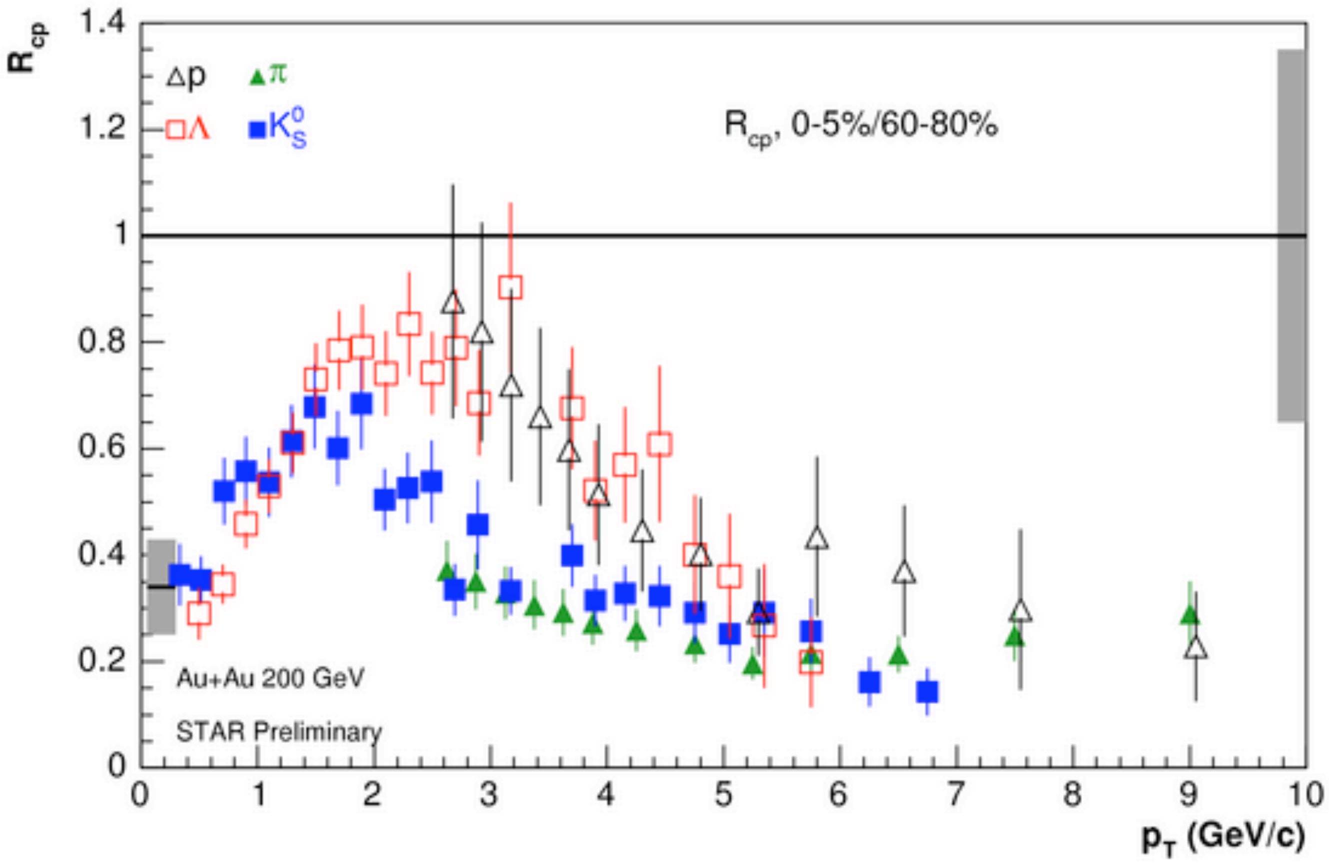
- established probe of final state suppression
  - sensitive to density of the medium
- very close to maximum suppression
  - provides only lower bound on density
- surface bias in high p_T hadron emission!

Dependence of Suppression on Geometry



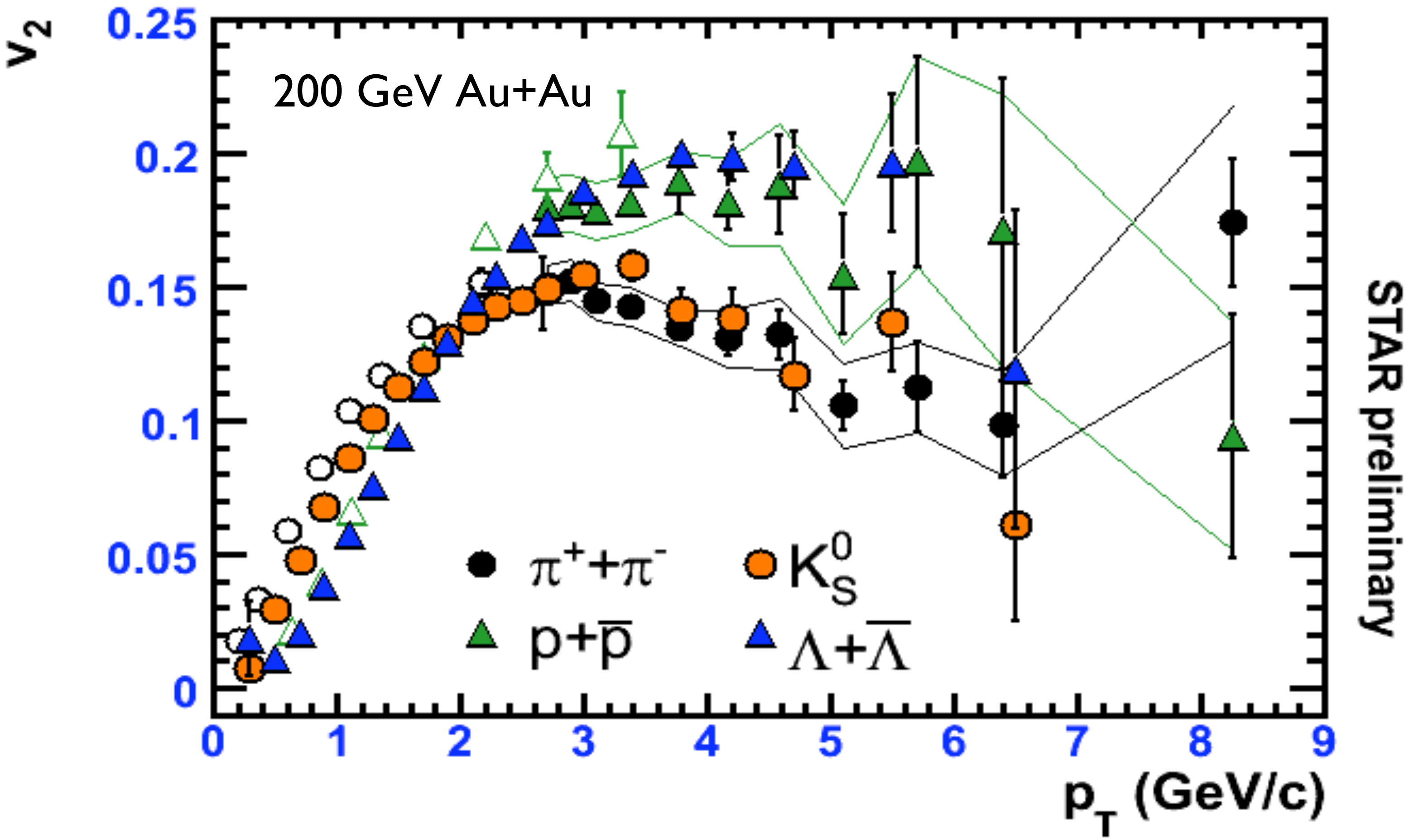
- Cu+Cu fit smoothly to trend of Au+Au
  - smaller uncertainties for small N_{part}
- universal dependence on N_{part}
  - does not strongly favour particular scaling law

Baryon vs. Meson R_{cp}



- baryon/meson separation at intermediate p_T
  - baryon enhancement
- explained by non-fragmentation contribution
  - e.g. recombination
- disappears at $p_T \approx 6$ GeV/c
  - fragmentation limit?
  - difference between q and g energy loss?

v_2 of Identified Hadrons



- finite v_2 at high p_T
- saturation and onset of decline at $p_T > 3$ GeV/c
- clear meson/baryon scaling at intermediate p_T
- v_2 from anisotropy in jet quenching
  - path length dependence

- meson/baryon scaling extends out to high p_T
- possibly: surface bias yields identical R_{AA} (R_{cp}) in central collisions for q and g, but difference still remains in v_2 from non-central collisions

PHENIX (open symbols):
Phys. Rev. Lett. *91*, 182301 (2003)

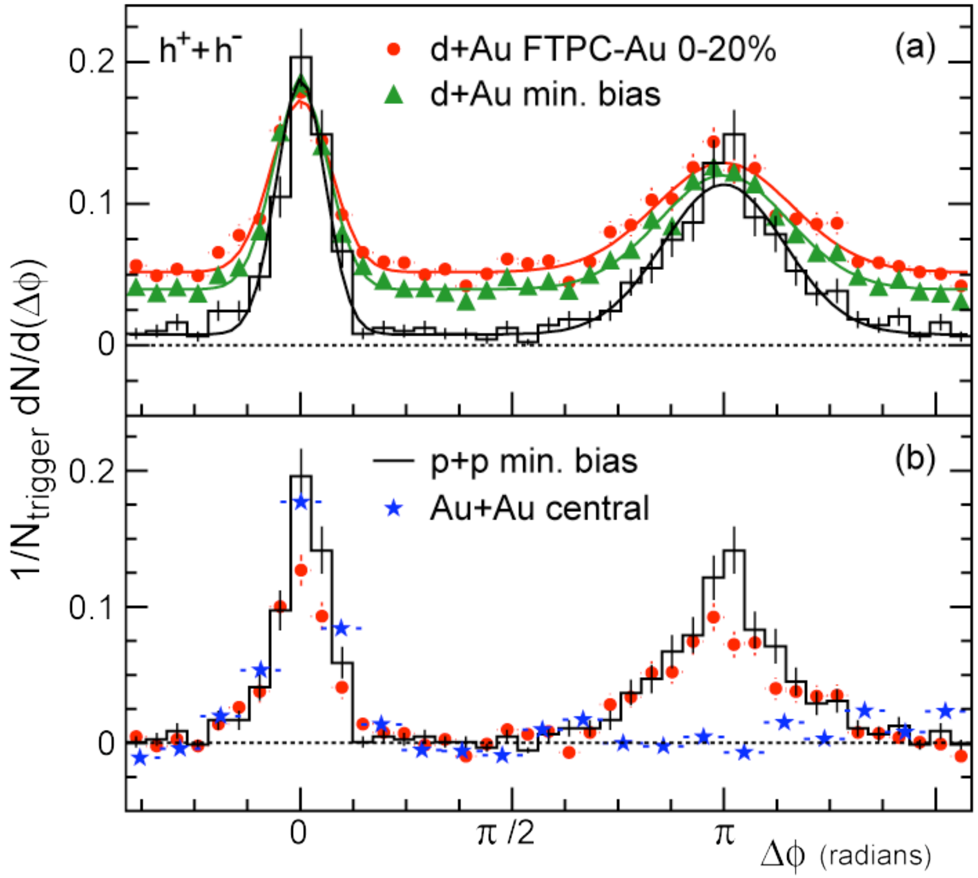
High-p_T Dihadron Correlations

Can we get an upper limit on the medium density?

How does fragmentation work after energy loss?

Dihadrons in Heavy Ion Collisions

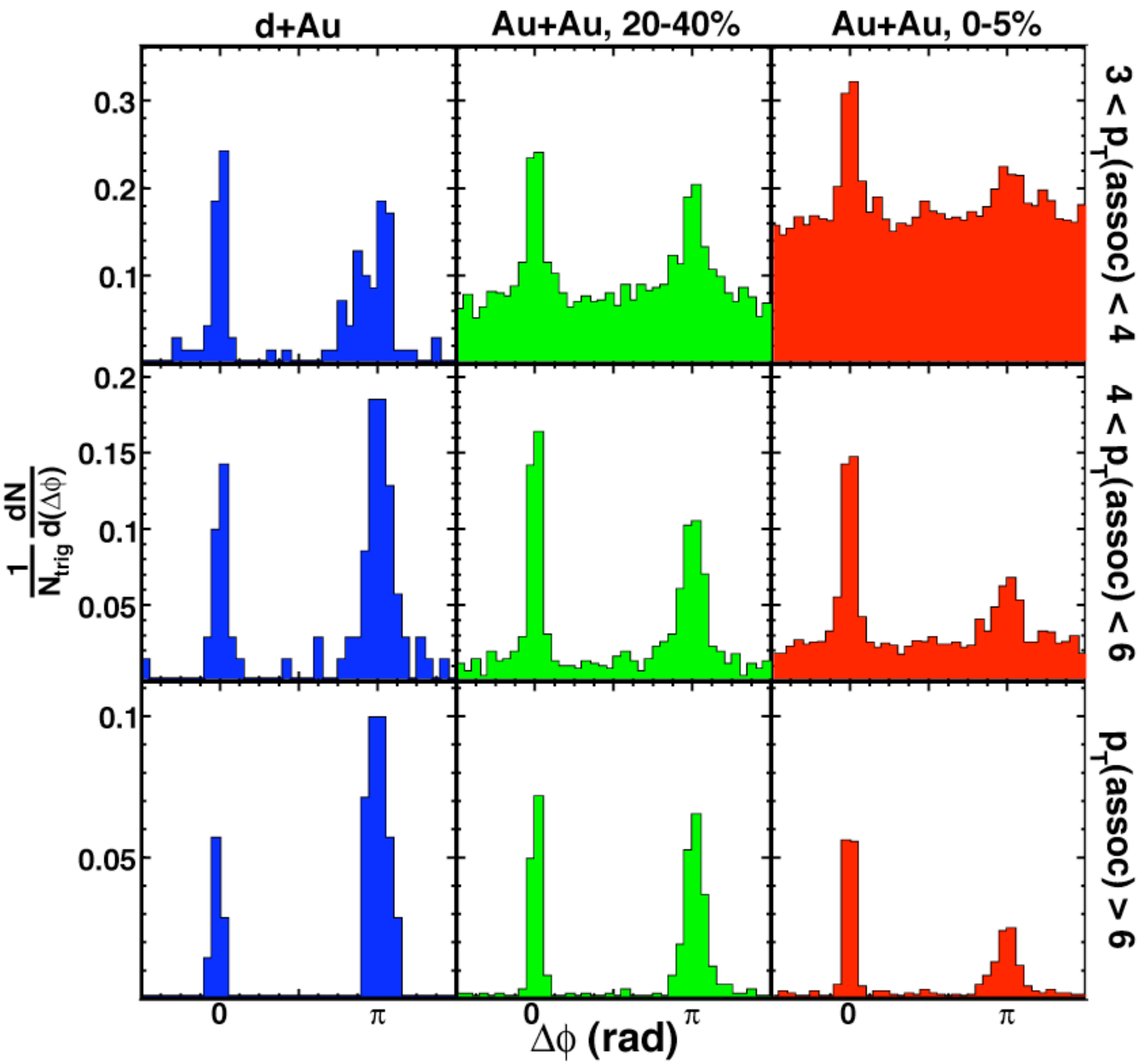
STAR - PRL91 (2003) 072304



- near-side correlation unchanged
- away-side peak suppressed in central Au+Au
  - consistent with surface emission
- distributions in d+Au similar to p+p
  - suppression is final state effect
- more intuitive hint for “jet” suppression, but quantitatively much more difficult

Emergence of Di-Jets

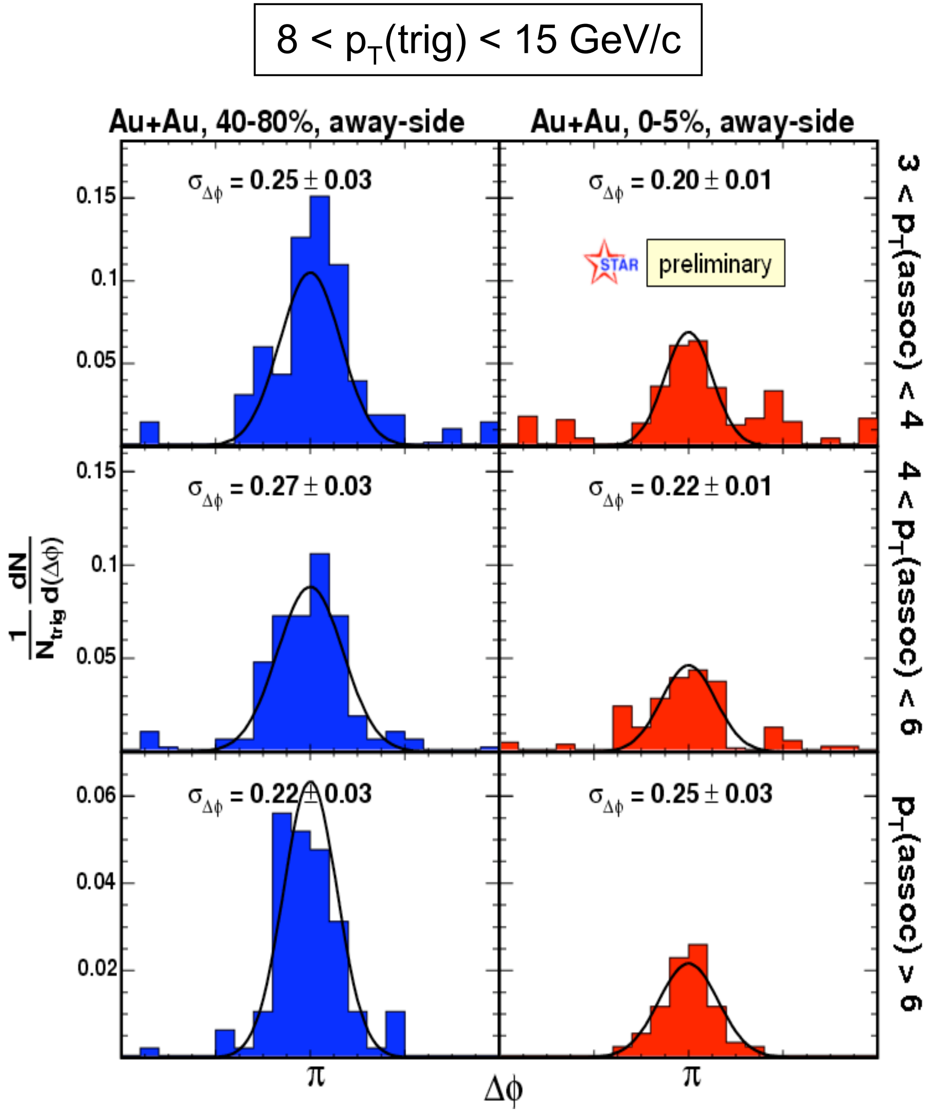
8 < p_T(trig) < 15 GeV/c



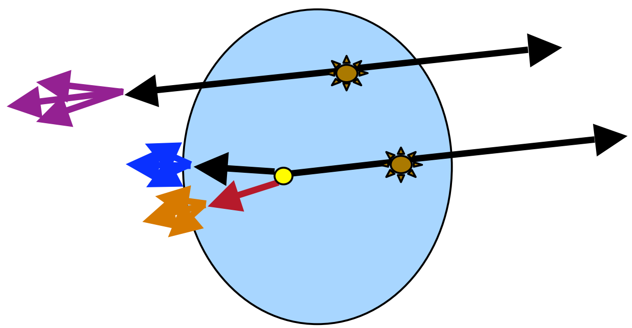
- clear away side peak even in central Au+Au for high trigger p_T
- background reduced for higher associated p_T
- little modification of near-side yield
- suppression of away-side yield apparent in central Au+Au

Adams et al., nucl-ex/0604018

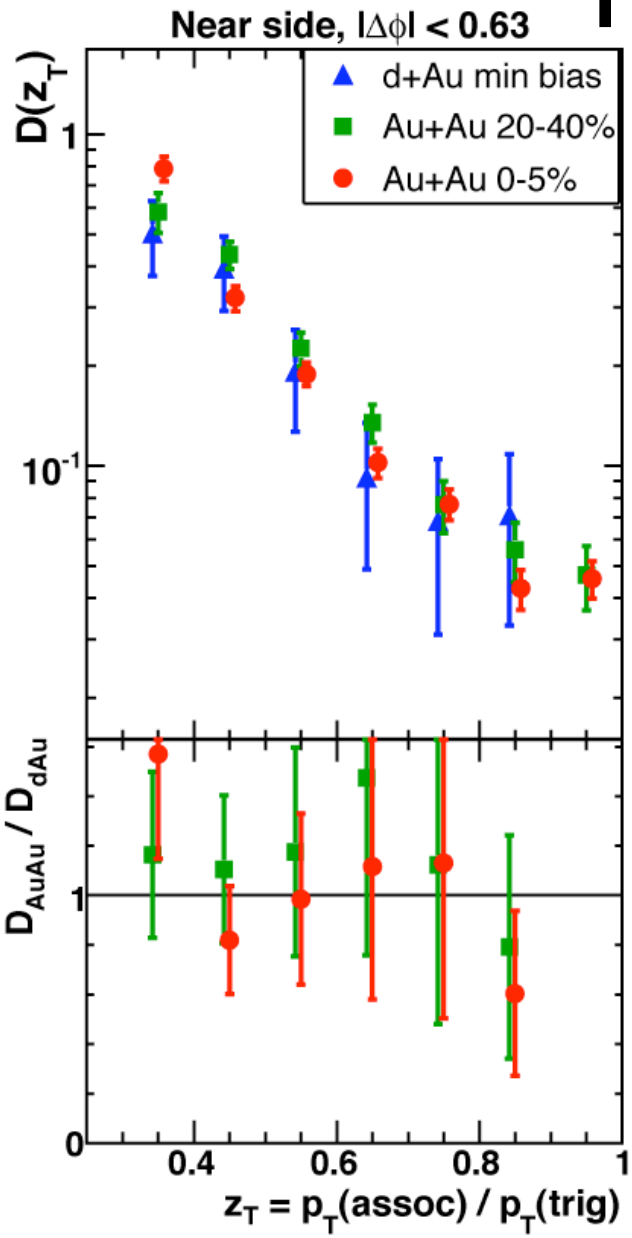
Width of Away-Side Peaks



- away-side widths similar for central and peripheral
- fragmentation as in vacuum?



Momentum Distribution of Near-Side Yield



Adams et al., nucl-ex/0604018

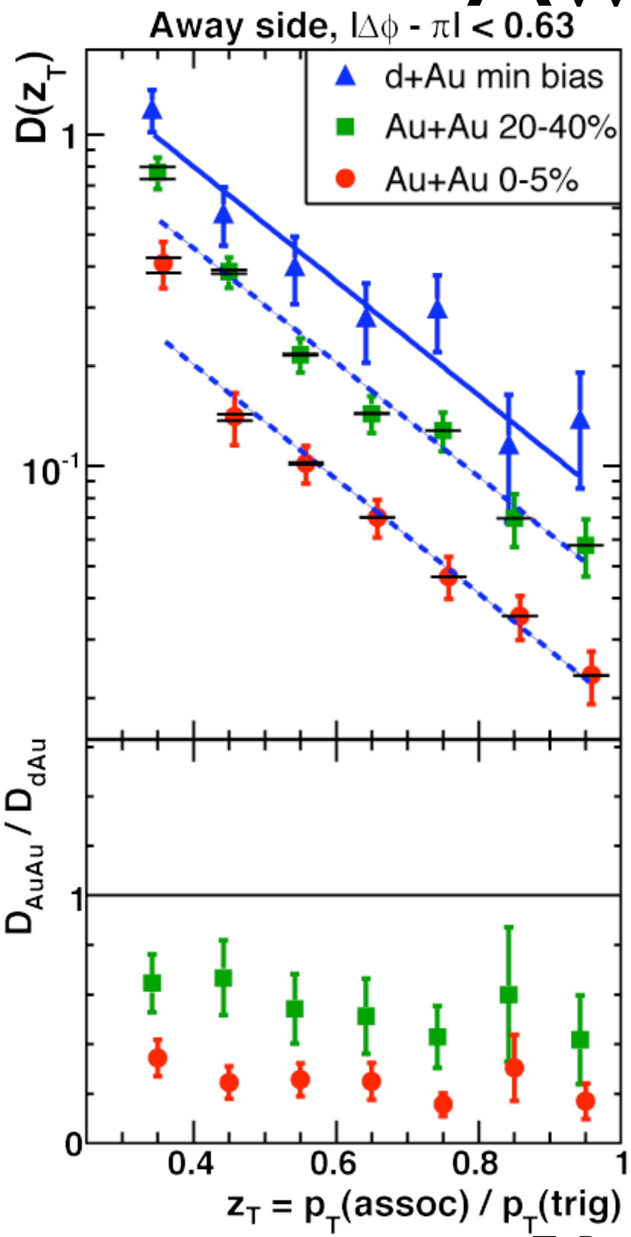
- Modified di-hadron fragmentation function (X.-N. Wang)

$$D^{h_1 h_2}\left(z_T, p_T^{trig}\right) = p_T^{trig} \frac{d\sigma_{AA}^{h_1 h_2} / dp_T^{trig} dp_T}{d\sigma_{AA}^{h_1} / dp_T^{trig}}$$

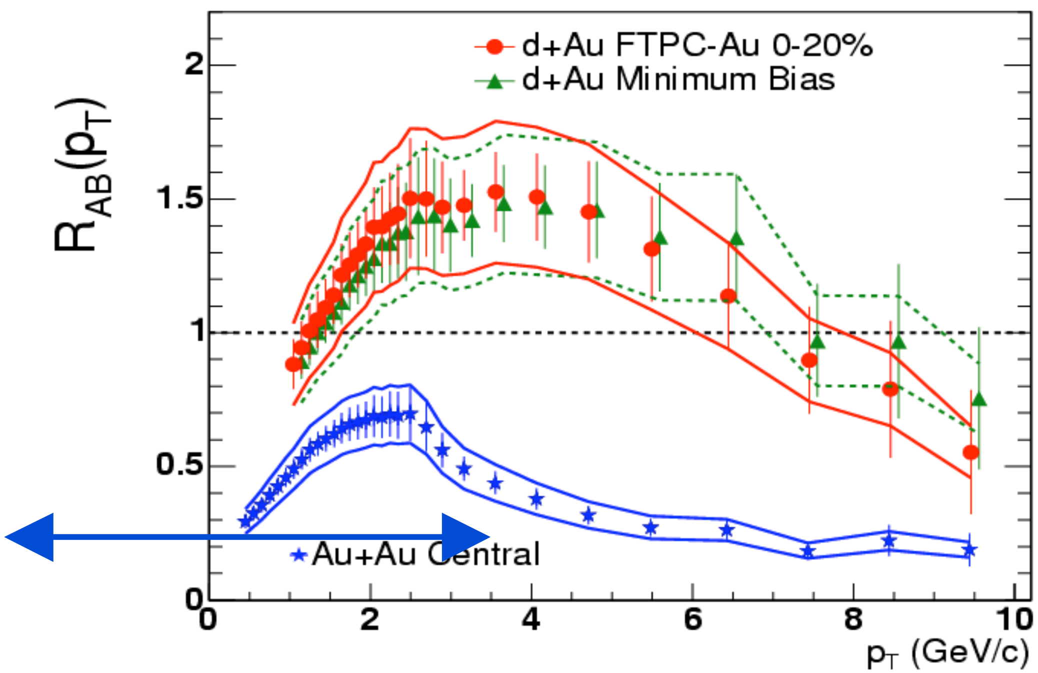
$$z_T \equiv \frac{p_T^{assoc}}{p_T^{trig}}$$

- near-side yield consistent with no modification
  – no dependence of ratio on z_T in measured range

Momentum Distribution of Away-Side Yield



- away-side yield strongly suppressed
  - level of R_{AA}
  - different surface bias?
  - upper limit on medium density obtainable?
- no dependence of ratio on z_T in measured range
  - vacuum fragmentation?



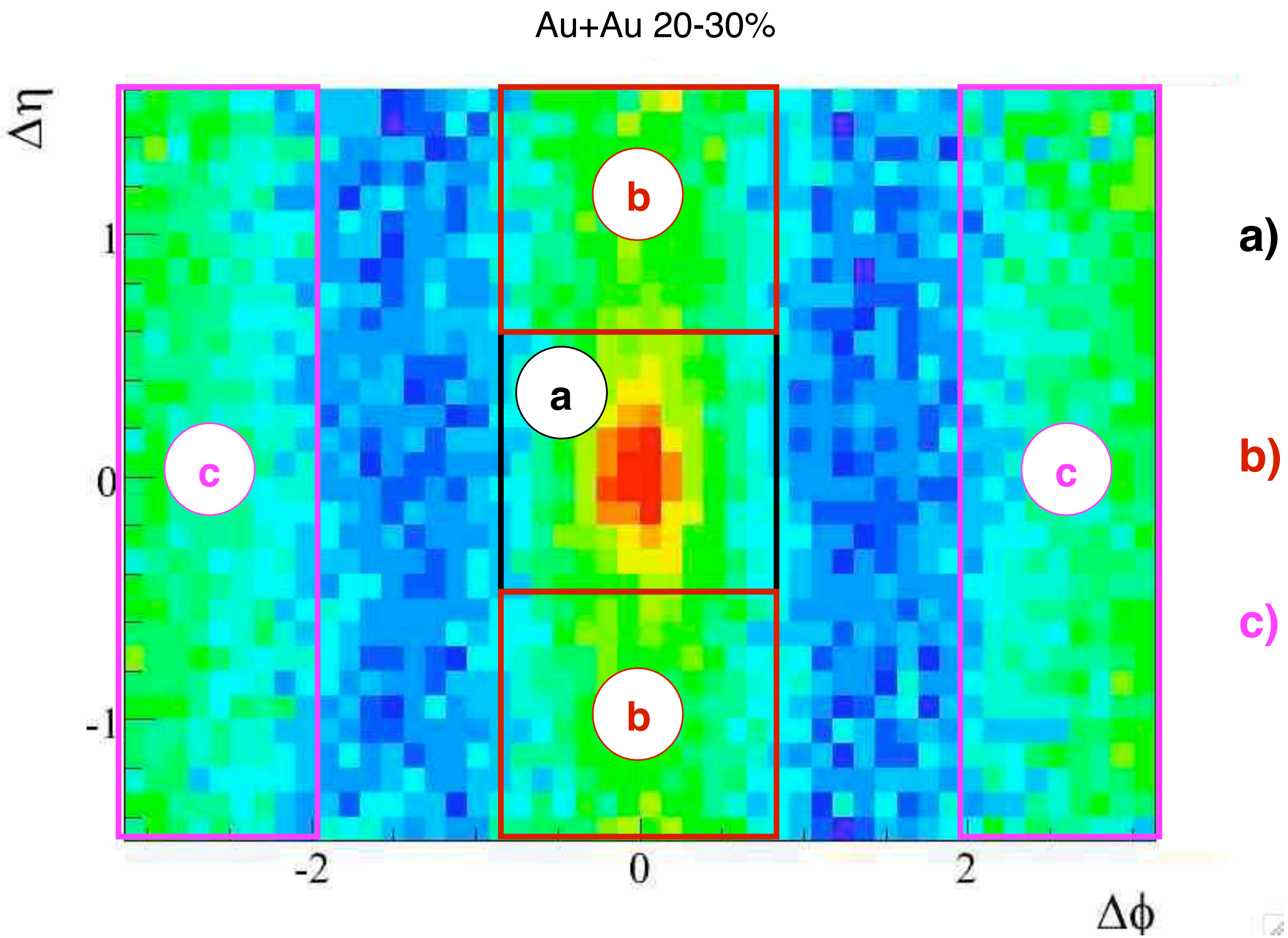
Adams et al., nucl-ex/0604018

Intermediate-p_T Near-Side

Do we see the coupling of the jet to the medium?

Can we test recombination models?

Near-Side Long-Range Δη Correlation: the Ridge



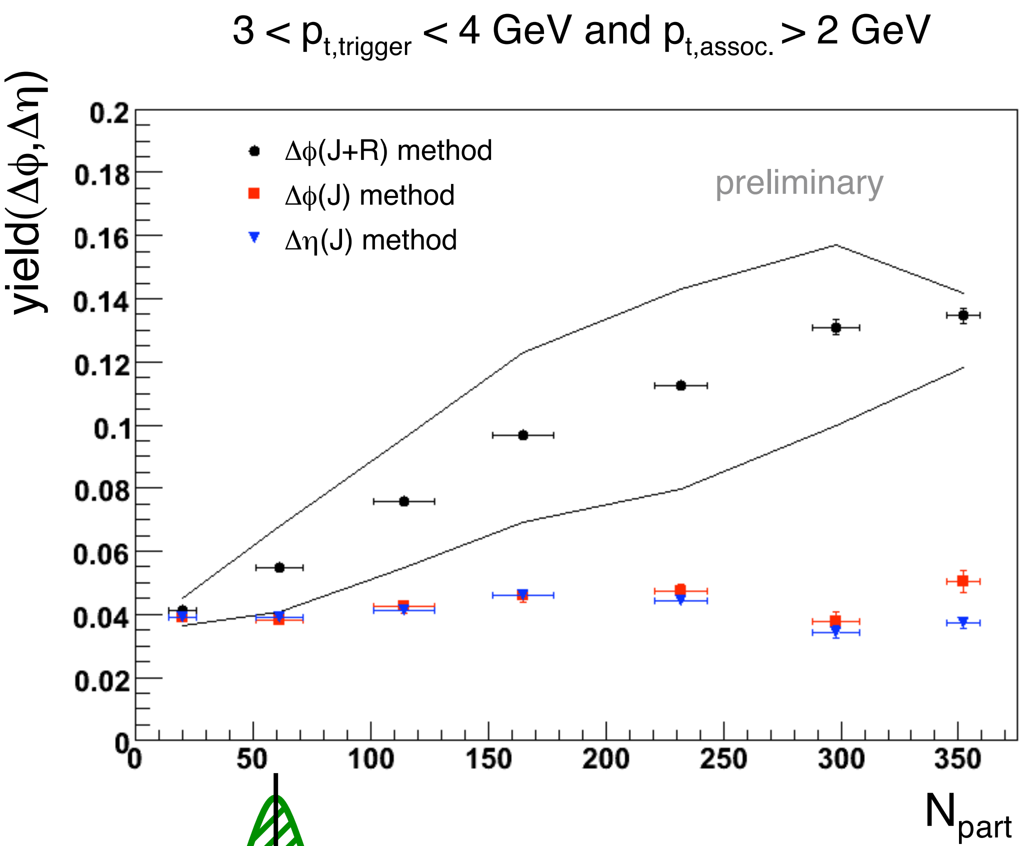
a) Near-side jet-like corrl.
+ ridge-like corrl.
+ v_2 modulated bkg.

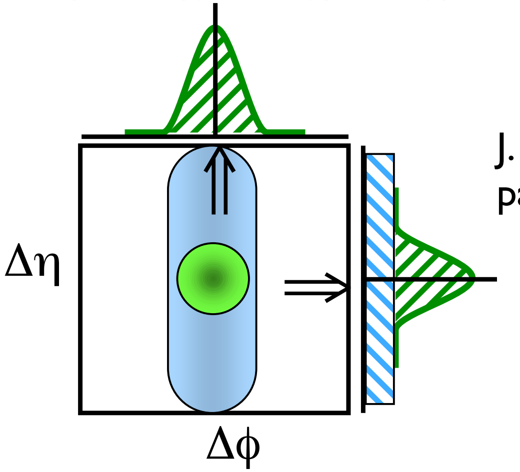
b) Ridge-like corrl.
+ v_2 modulated bkg.

c) Away-side corrl.
+ v_2 modulated bkg.

T. Peitzmann, Hard Probes 2006, Asilomar

Centrality Dependence of the Ridge

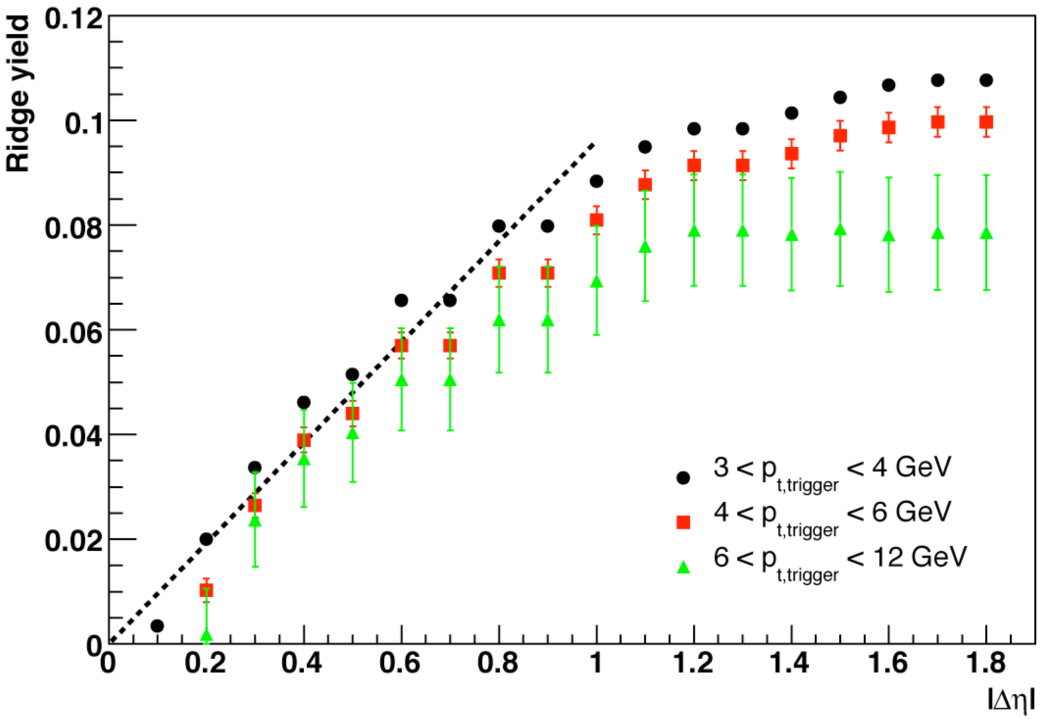




J. Putschke et al., parallel talk

- yield of associated particles can be separated into a jet-like yield and a ridge yield
  - jet-like yield consistent in η and φ and independent of centrality
  - ridge yield increases with centrality

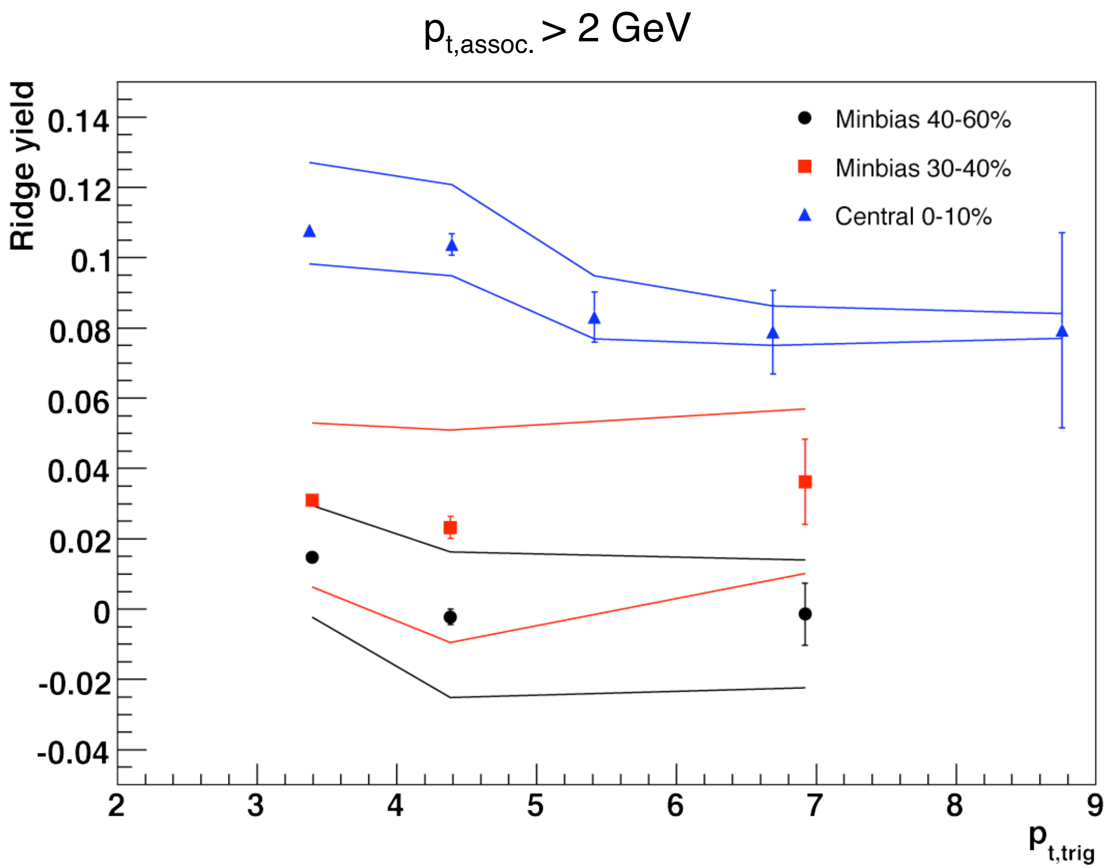
Rapidity Dependence



- approximately linear dependence on rapidity
  - longitudinal scaling
    - relation to longitudinal flow?
  - shorter range for larger trigger p_T

J. Putschke et al., parallel talk

Dependence on Trigger p_T

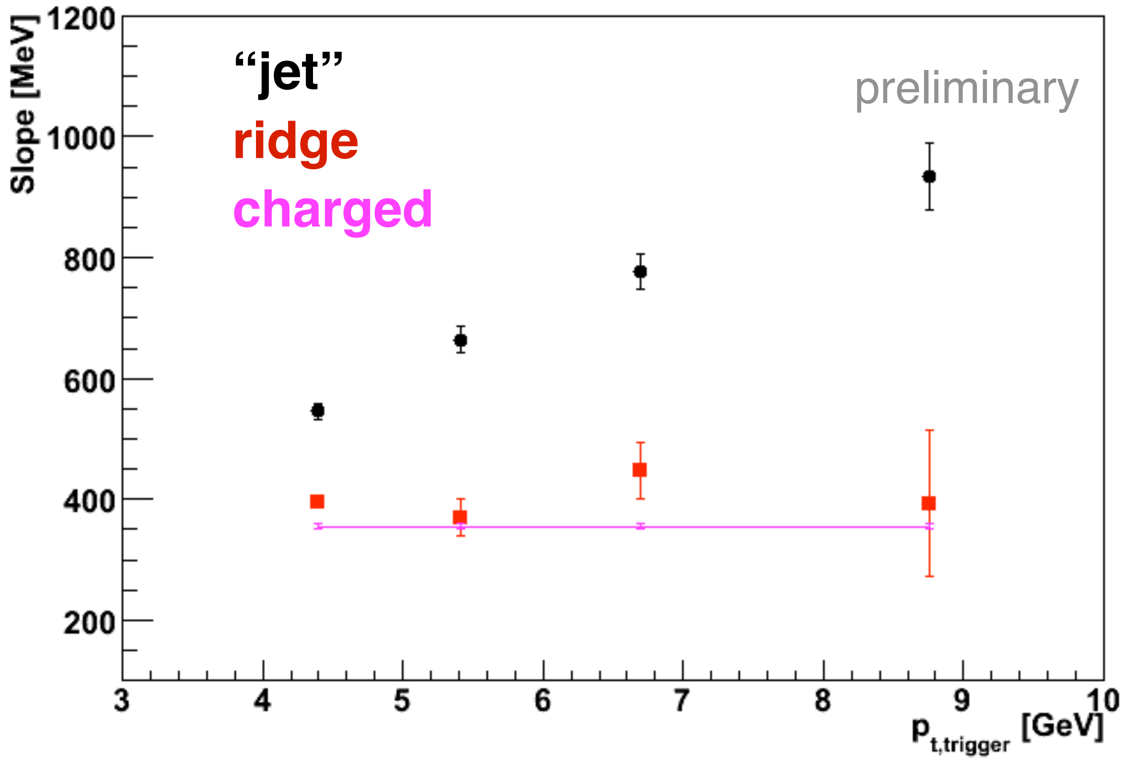


- yield significant up to p_T = 9 GeV/c in central
  - clearly jet-related
- no strong dependence on trigger hadron momentum
  - increase of jet-like yield ⇒ decrease of relative yield

J. Putschke et al., parallel talk

Shape of Associated Particle Spectra

$$dN/dp_t \propto p_t e^{-p_t/T}$$



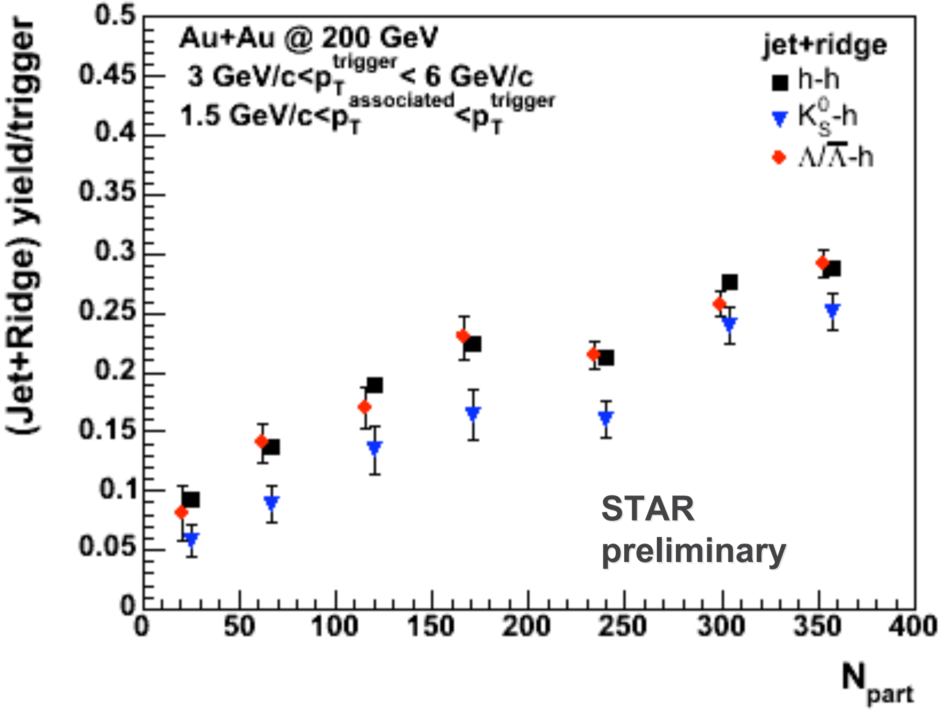
- jet-like spectra harder than inclusive
  - flatter for higher trigger p_T
- ridge spectra similar to inclusive
  - slightly larger slope
  - approximately independent of trigger p_T

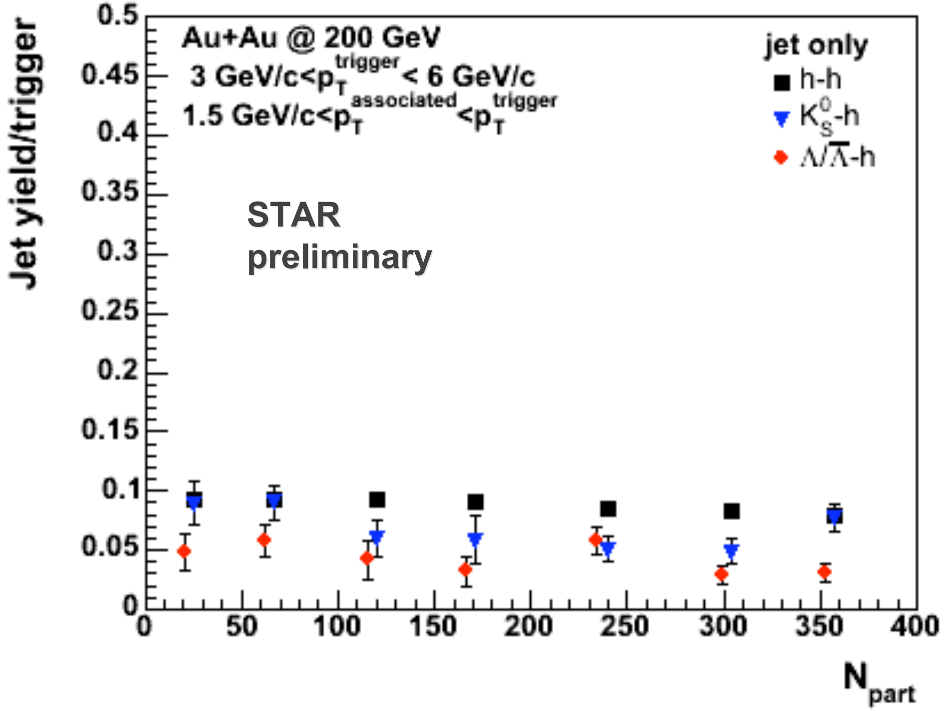
J. Putschke et al., parallel talk

Recombination and Dihadron Correlations

- large baryon yield at intermediate p_T explained by recombination models
- difference in correlation structure expected
  - naïve expectation from pure thermal reco: no correlation
  - more realistic models: some correlation due to thermal-shower reco (R. Hwa)
- hadrons from recombination should show a modified correlation
- larger fraction of baryons produced from recombination (compared to mesons)
- stronger modification of correlation structure expected for baryon triggers

Identified Hadron Triggers

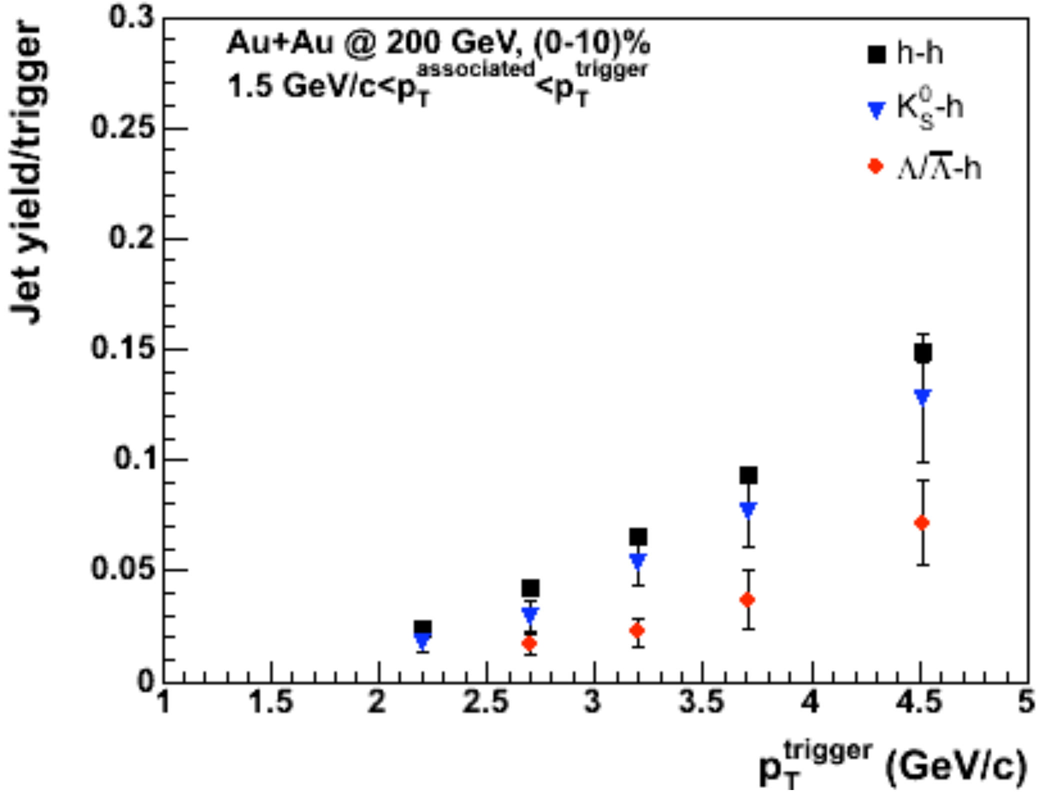




- total associated yield increases with centrality: ridge!
- jet-like yield independent of centrality
  - differences for strange particles

J. Bielcikowa et al., parallel talk

Identified Hadron Triggers



- less associated jet-like yield for Λ
  - higher ridge yield for Λ
  - consistent with recombination?
- attention when extracting correlation strength in $\Delta\phi$ only!

J. Bielcikowa et al., parallel talk

Interpretation of the Ridge

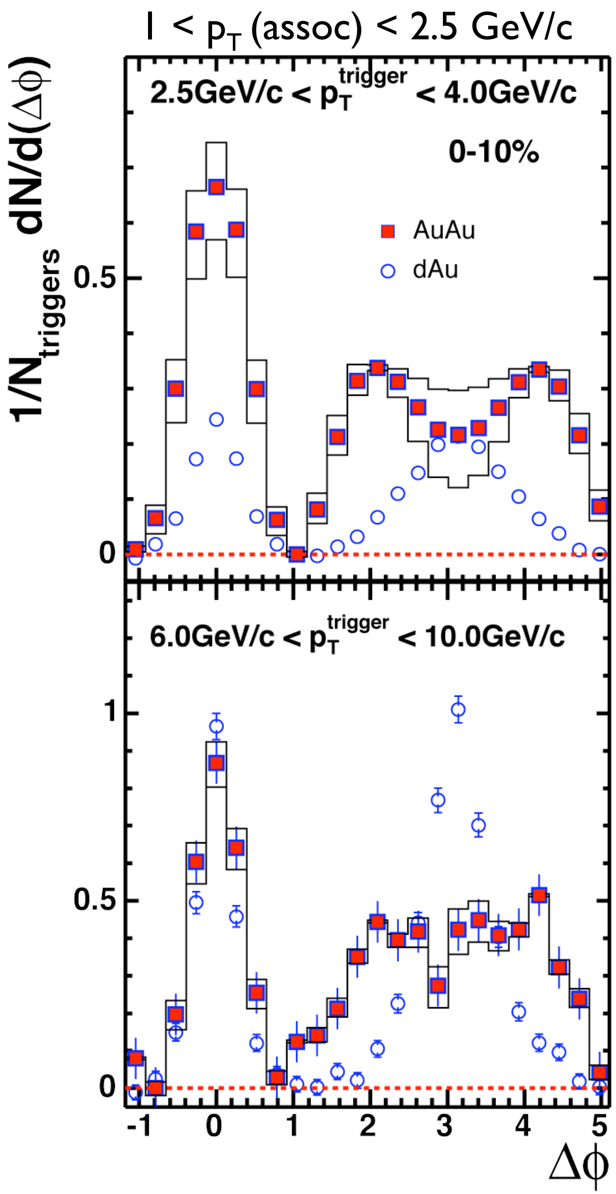
- coupling of high energy parton to longitudinal flow (Armesto et al, nucl-ex/0405301)
  - expect broadening but not plateau
- correlation from radial flow (Voloshin nucl-th/0312065)
  - not expected at high p_T
- thermal recombination + local heating from energy loss (Chiu & Hwa, Phys. Rev. C72 034903, 2005)
  - qualitatively consistent
- more general:
  - ridge is jet-related structure with properties similar to bulk
  - early coupling: before longitudinal expansion
  - local energy (heating) or momentum transfer (collective flow)
- Does ridge measure the amount of energy transferred to the bulk?

Intermediate-p_T Away-Side

Where does the jet energy go?

Is their conical flow?

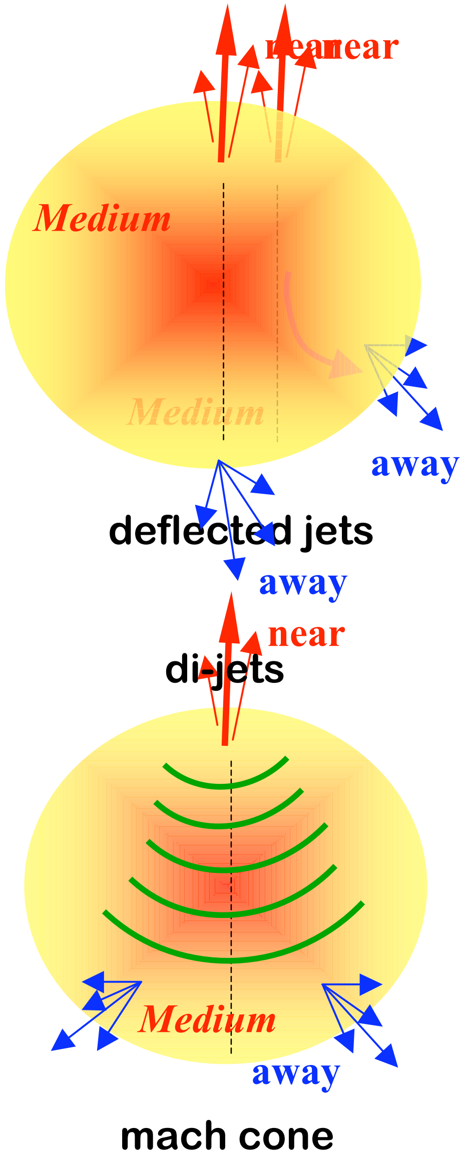
Two-Particle Correlations (Mach Cone?)

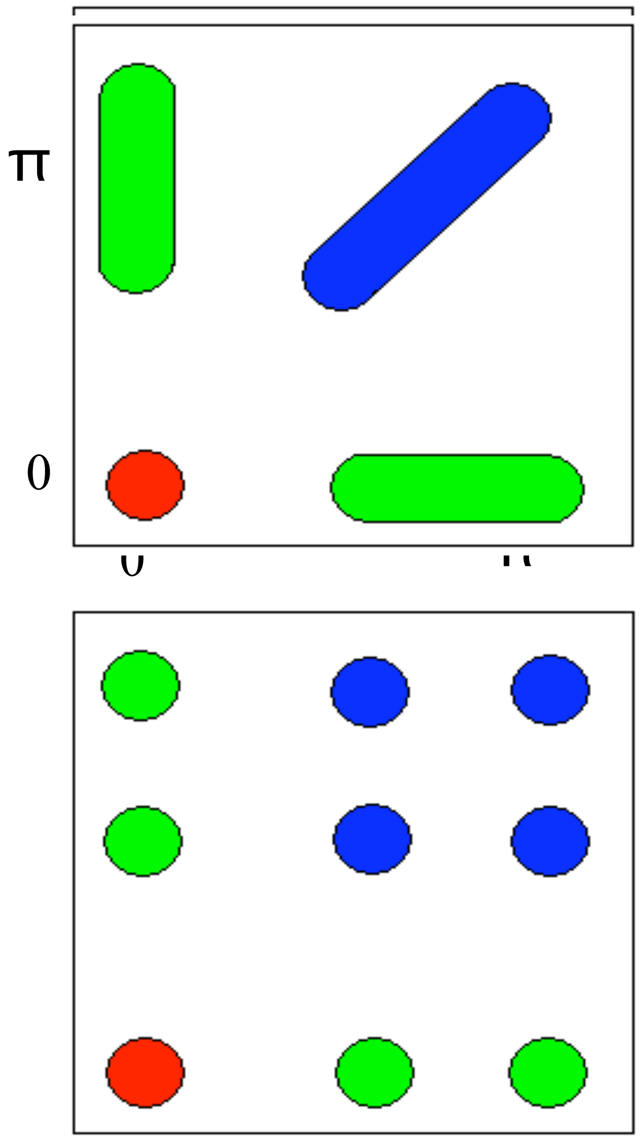


- broad away-side distribution in central Au+Au
  - enhanced yield for lower p_T
  - consistent with two-peak structure
    - Mach cone or deflected jets?
      $\Rightarrow$ study 3-part. correlation
  - sensitive to elliptic flow subtraction
- dependence on trigger p_T?
- enhanced yield for near-side
  - quantitatively consistent with ridge
  - near-side enhancement only ridge?
    $\Rightarrow$ vacuum fragmentation?

M. Horner et al., Poster

Conical Flow vs Deflected Jets

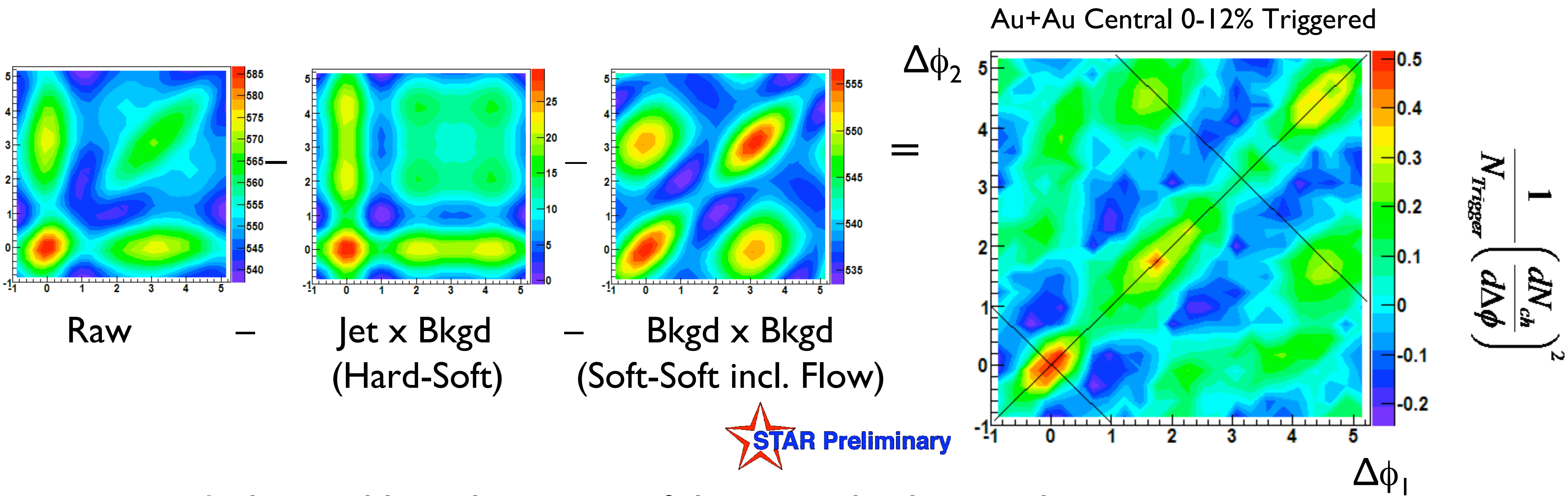




T. Peitzmann, Hard Probes 2006, Asilomar

J. Ulery et al., parallel talk

Three-Particle Correlations



- signal obtained by subtraction of dominant backgrounds
  - flow components, jet-related two-particle correlation
- improved analysis compared to QM (e.g. high statistics)
  - additional check with cumulant analysis under way
  - careful: different assumptions on background normalisation!
- clear elongation (jet deflection)
- off-diagonal signal related to mach cone?

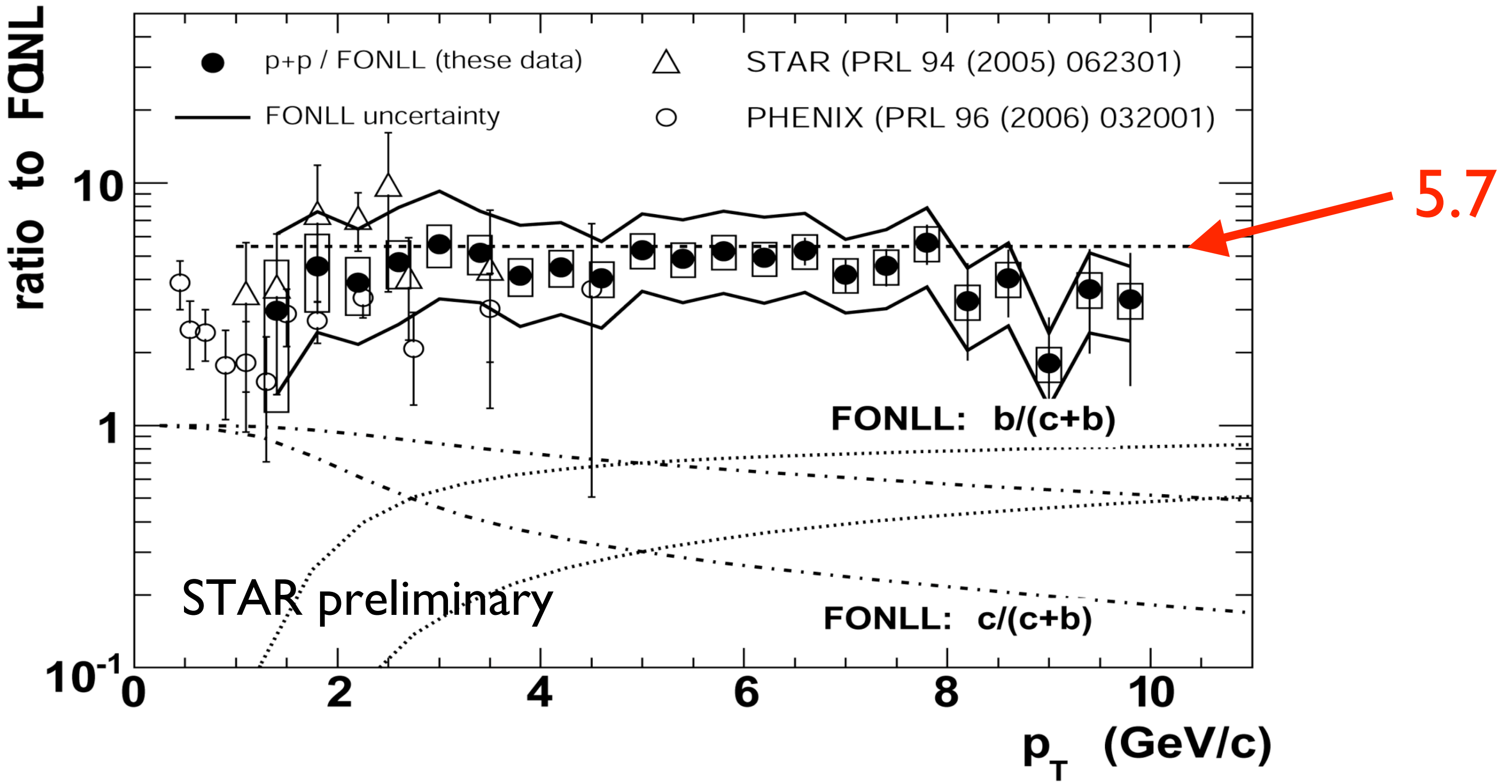
J. Ulery et al., parallel talk

Heavy Flavour

Do we understand heavy flavour production?

What is the energy loss mechanism?

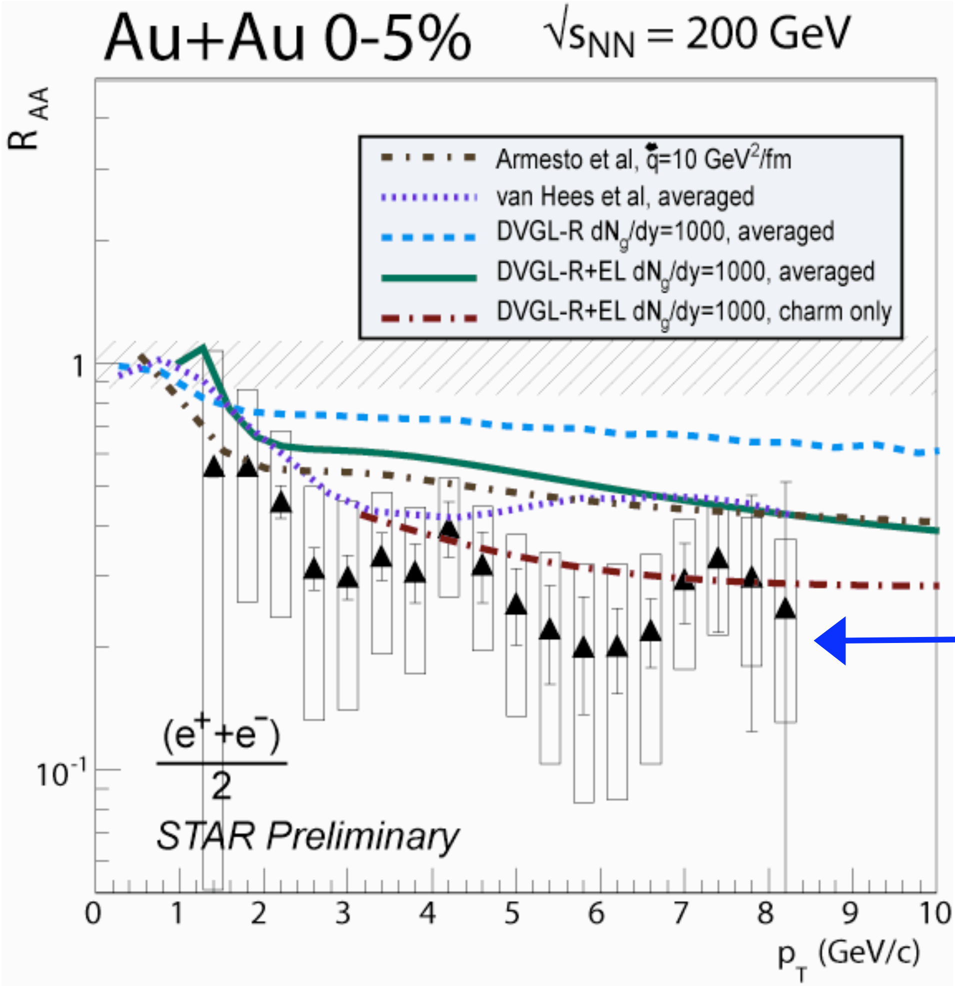
Electrons in p+p Compared to pQCD



- single (non-photonic) electrons mainly from c and b
- pQCD (FONLL) scaled by K-factor ≈5.7 to match the data
- Ratio Data/pQCD is independent of p_T for p_T < 8 GeV/c
  - same K-factor for charm and beauty?

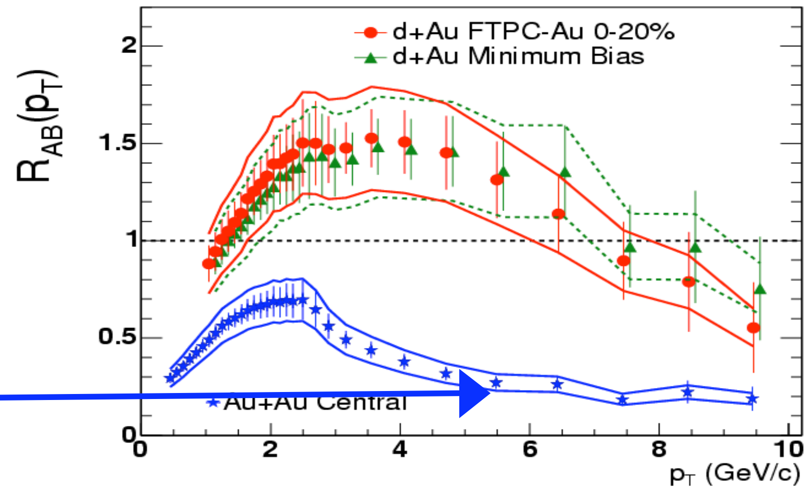
J. Bielcik et al., parallel talk

Single Electron R_{AA}



Armesto et al. hep-th/0511257
van Hees et al. Phys. Rev. C 73, 034913 (2006)
Wicks et al. (DVGL) hep-th/0512076

Charged Hadron R_{AA}



- R_{AA} to 10 GeV/c in non-photonic electrons
- suppression is approximately the same as for light hadrons

theoretical description needs:

- extremely high density or
- significant contributions of collisional energy loss and dominance of charm up to high p_T

J. Bielcik et al., parallel talk

The Future: Photons

The reference probe.

Can we tag the initial jet energy?

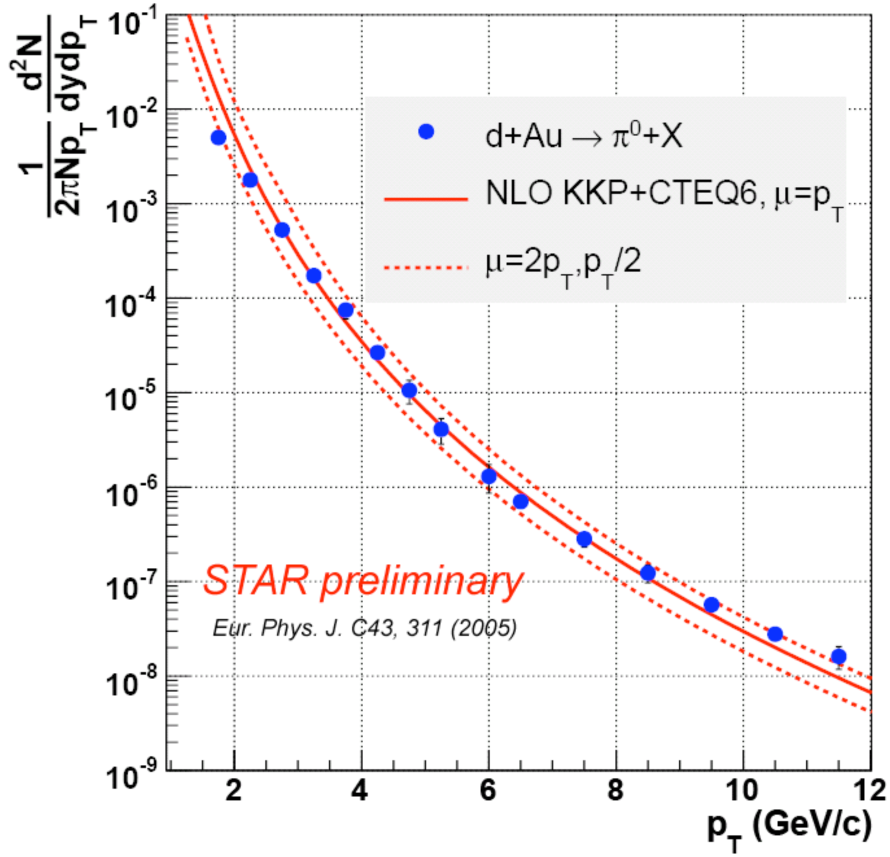
Can we measure energy loss?

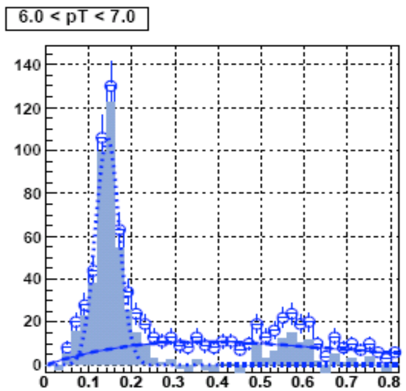
NIKHEF Universiteit Utrecht

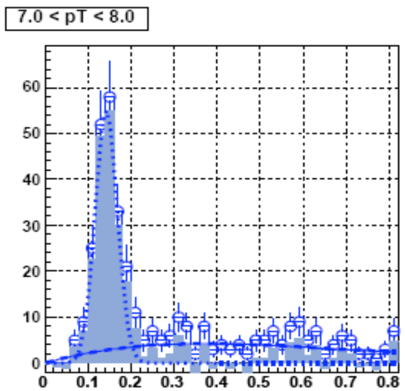
STAR

Neutral Pion Spectra

d+Au 2003

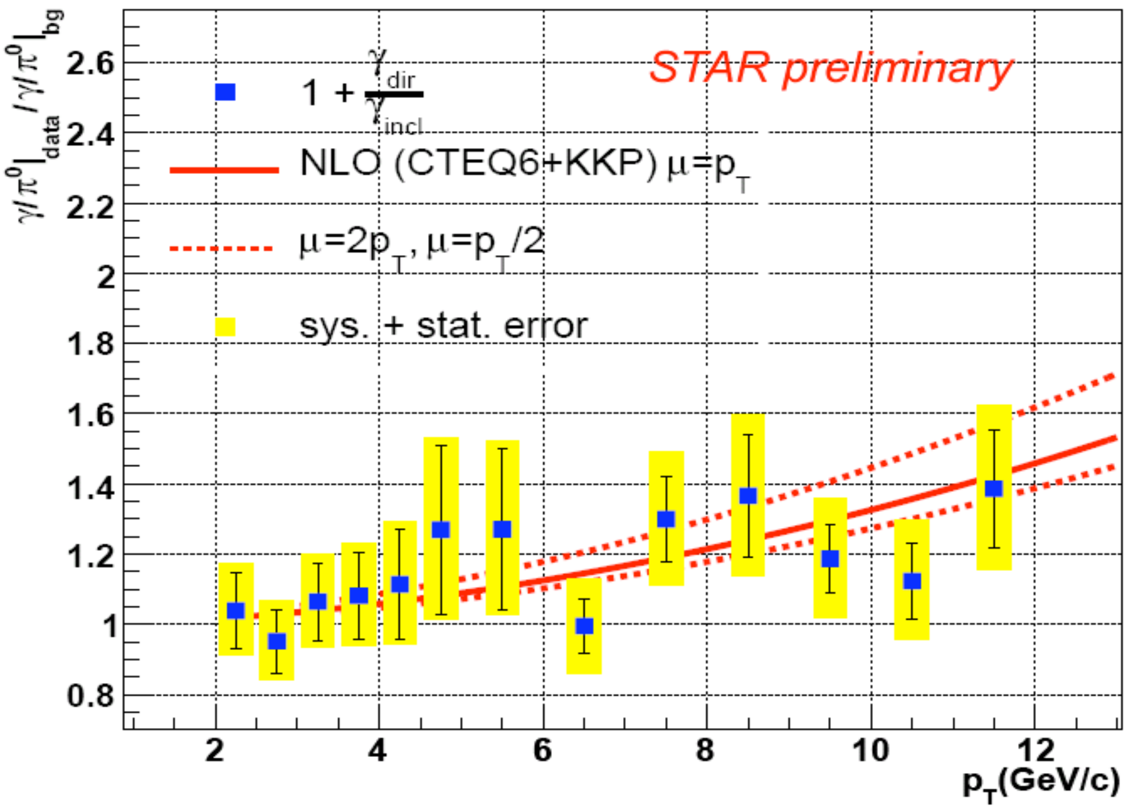






- measured with STAR Barrel EMC
- reconstruction of two-photon invariant mass
- agreement with NLO pQCD in d+Au
- used as input for direct photon analysis
  - statistical subtraction of decay background

Direct Photons in d+Au

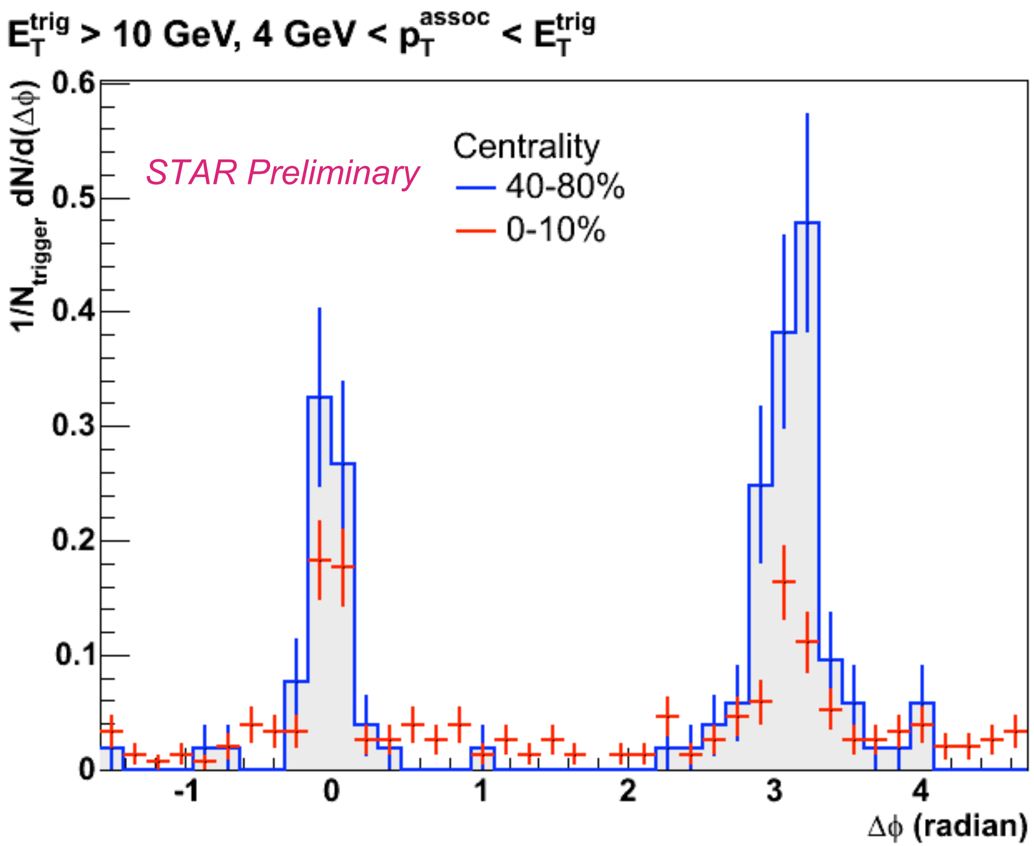


$$R \equiv \frac{\left(\gamma_{incl} / \pi^0\right)_{measured}}{\left(\gamma_{decay} / \pi^0\right)_{simulated}} \approx 1 + \frac{\gamma_{direct}}{\gamma_{decay}}$$

- proof of principle measurement with STAR Barrel EMC
- setting a baseline for Au+Au
- consistent with NLO pQCD
- reduction of systematic errors needed to extract spectrum

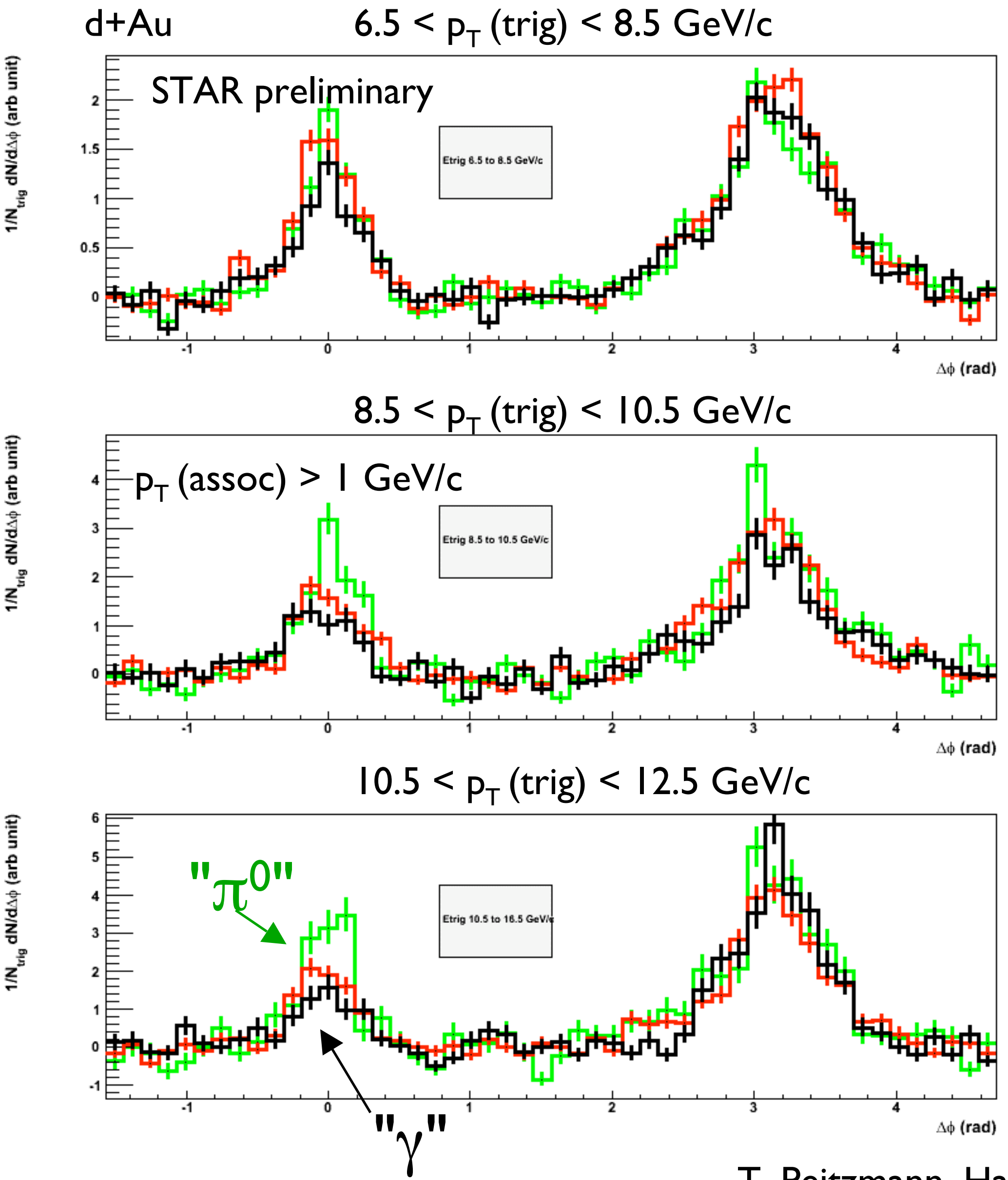
NIKHEF Universiteit Utrecht STAR

Towards γ-Jet in Au+Au



- photon tag
  - potentially clean jet preparation
- clear near-side and away-side correlation peaks
- strong contamination from π^0 decay photons
  - reduction in near-side strength compatible with direct photon component
- work in progress …

Shower Shape Analysis in d+Au



- charged hadrons associated with high E_T EM shower
- shower width selects π^0 and γ candidates
- measure associated yield for π^0 triggers
  - reduction of yield can be used to estimate direct γ contribution in other samples
- possibility to enrich trigger sample with direct γ!

S. Chattopadhyay et al., parallel talk

Summary

- fragmentation regime reached at p_T = 6 GeV/c
  - elliptic flow consistent?
- upper limit on density from di-hadron correlations?
- jet-like yield consistent with vacuum fragmentation
  - width, yield and momentum spectrum unchanged
- enhancement on near-side due to soft correlation
  - long range in η (ridge)
  - ridge yield indicates amount of energy loss?
  - careful in $\Delta\phi$-only analysis!
- softening and broadening on the away-side
  - 2-part. correlations consistent with Mach cone
  - 3-part. correlations show jet-deflection - Mach cone signal not well established
- heavy flavour
  - importance of c and b
  - energy loss mechanism?
- photons
  - direct photons in d+Au
  - getting ready to exploit EMC capabilities for photon tagged jets

The *STAR* Collaboration

U.S. Labs:
Argonne, Lawrence Berkeley, and Brookhaven National Labs

U.S. Universities:
UC Berkeley, UC Davis, UCLA, Caltech, Carnegie Mellon, Creighton, Indiana, Kent State, MIT, MSU, CCNY, Ohio State, Penn State, Purdue, Rice, Texas A&M, UT Austin, Washington, Wayne State, Valparaiso, Yale

Brazil:
Universidade de Sao Paolo

China:
IHEP - Beijing, IPP - Wuhan, USTC, Tsinghua, SINAP, IMP Lanzhou

Croatia:
Zagreb University

Czech Republic:
Nuclear Physics Institute

England:
University of Birmingham

France:
Institut de Recherches Subatomiques Strasbourg, SUBATECH - Nantes

Germany:
Max Planck Institute – Munich University of Frankfurt

India:
Bhubaneswar, Jammu, IIT-Mumbai, Panjab, Rajasthan, VECC

Netherlands:
NIKHEF/Utrecht

Poland:
Warsaw University of Technology

Russia:
MEPHI – Moscow, LPP/LHE JINR – Dubna, IHEP – Protvino

South Korea:
Pusan National University

Switzerland:
University of Bern